

**USING FOREST MANAGEMENT
TO AUGMENT STREAMFLOW**



SUMMARY OF RESEARCH RESULTS FROM:

**COWEETA HYDROLOGIC LABORATORY
SOUTHERN RESEARCH STATION
FOREST SERVICE, USDA
3160 COWEETA LAB ROAD
OTTO NC 28763**

CONCLUSIONS FROM
WATER YIELD STUDIES
AT COWEETA HYDROLOGIC LABORATORY

Forest cuttings increase streamflow.

Greatest increases are in fall and early winter.

Increases decline as vegetation regrows.

Water use is proportional to leaf area and thus to vegetation growth.

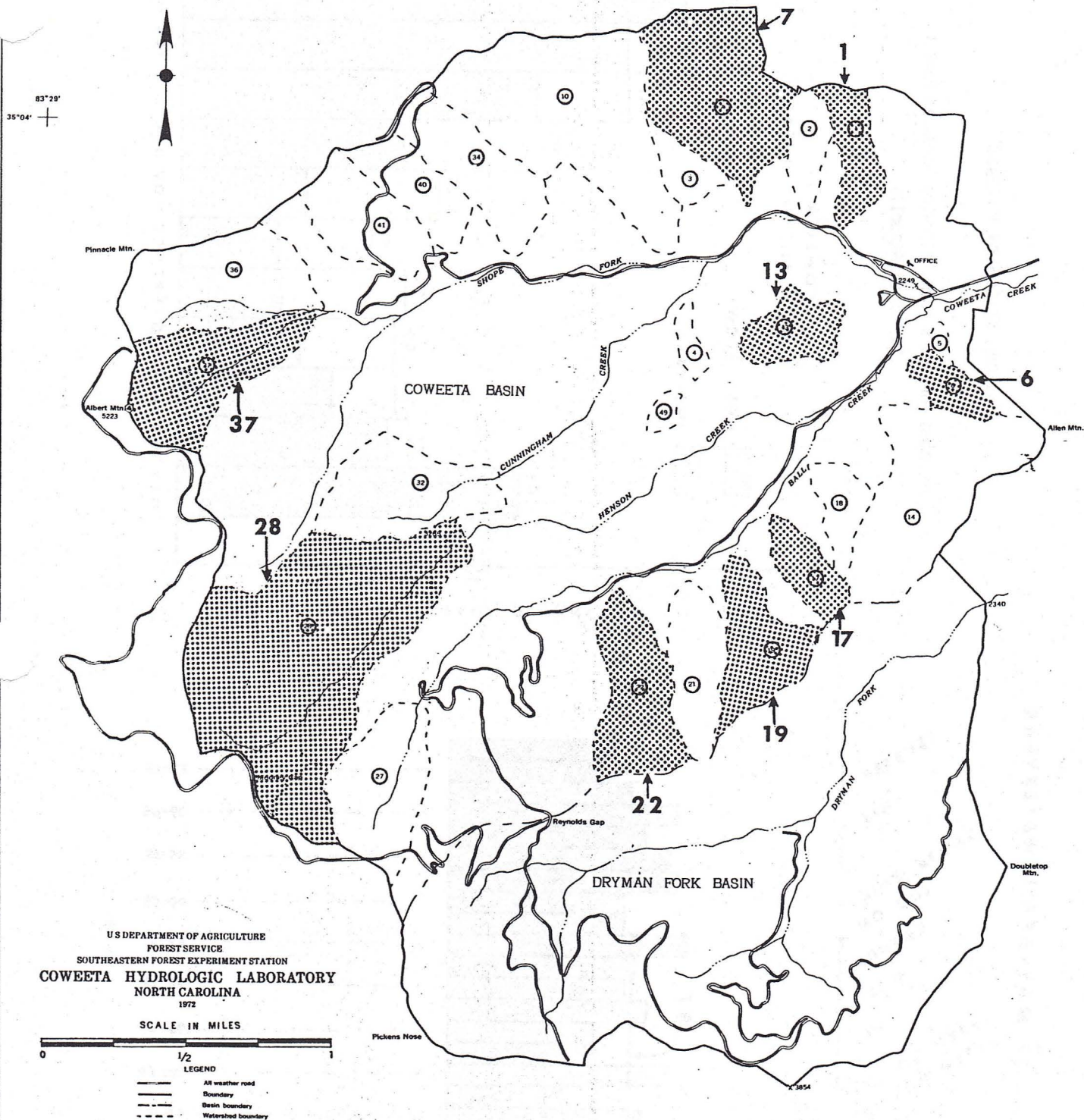
Increases are greatest on north-facing slopes – thus increases can be predicted from potential solar radiation.

Cutting in the riparian zone yields only minor flow increase.

Storm flows are increased slightly – the majority of the flow increase comes as nonstorm flows.

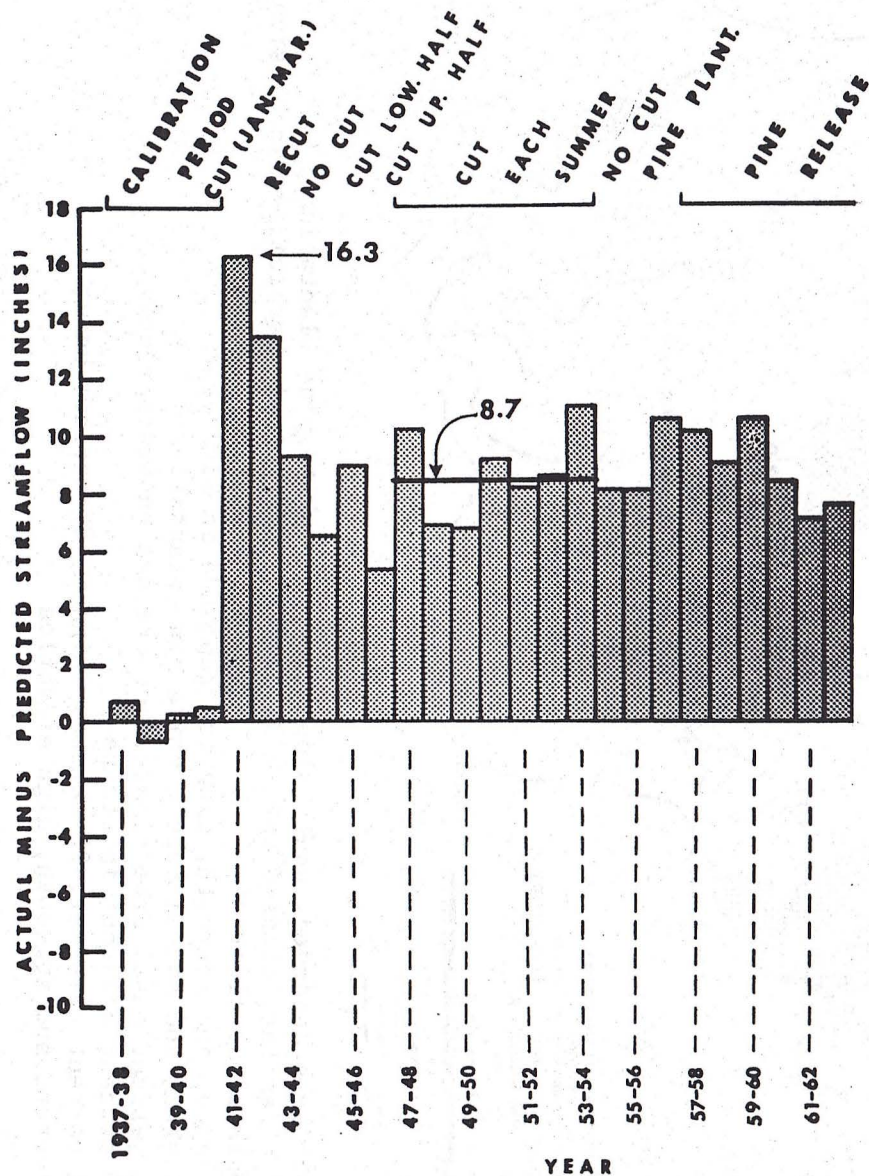
Conifer species use more water than deciduous forests – this greater use occurs in the dormant season.

LOCATION OF WATER YIELD EXPERIMENTS AT COWEETA



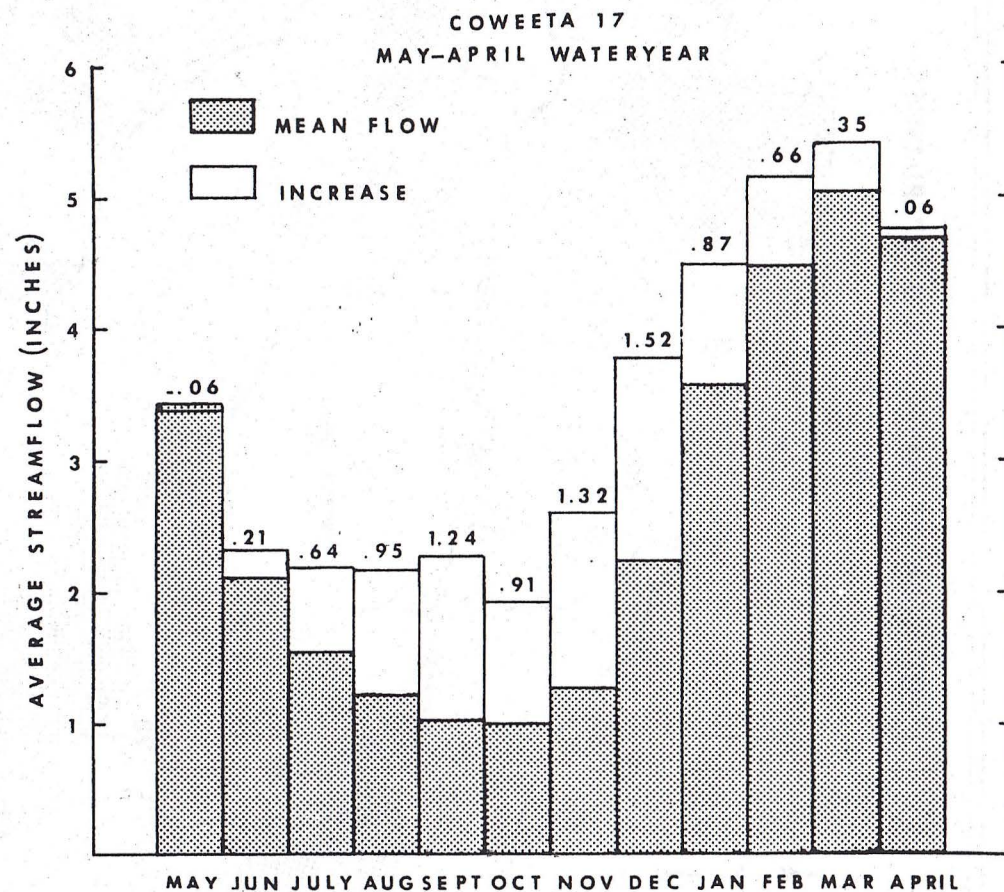
- 1 Cove site deadened, south slope clearcut, white pine plantation
- 6 Riparian cut, cleared and Ky-31 planted, fertilized, herbicided, succession vegetation
- 7 South slope clearcut
- 13 Clearcut and regrowth, clearcut repeated in 23rd year
- 17 Clearcut and annual recut, white pine plantation
- 19 22 percent basal area clearcut - evergreen understory only
- 22 50 percent clearcut in strips
- 28 51 percent clearcut, 22 percent thinned, 27 percent uncut
- 37 Clearcut and regrowth, high elevation

COWEETA 17 MAY-APRIL WATERYEAR

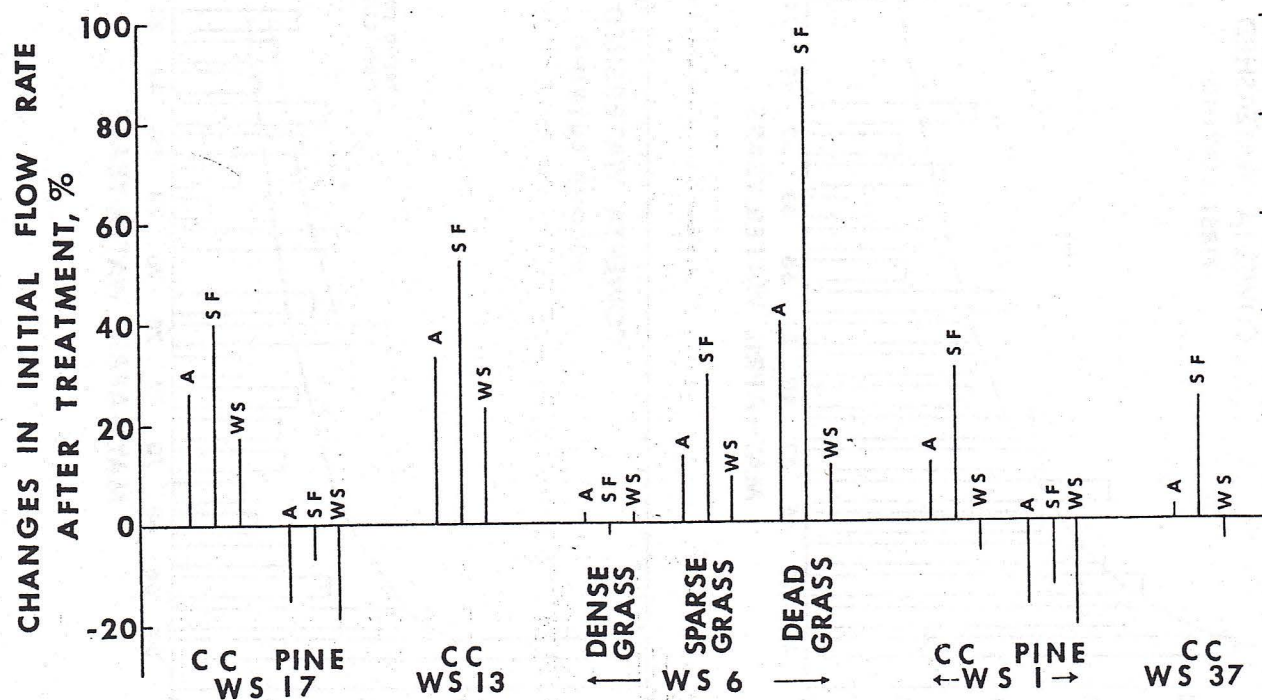
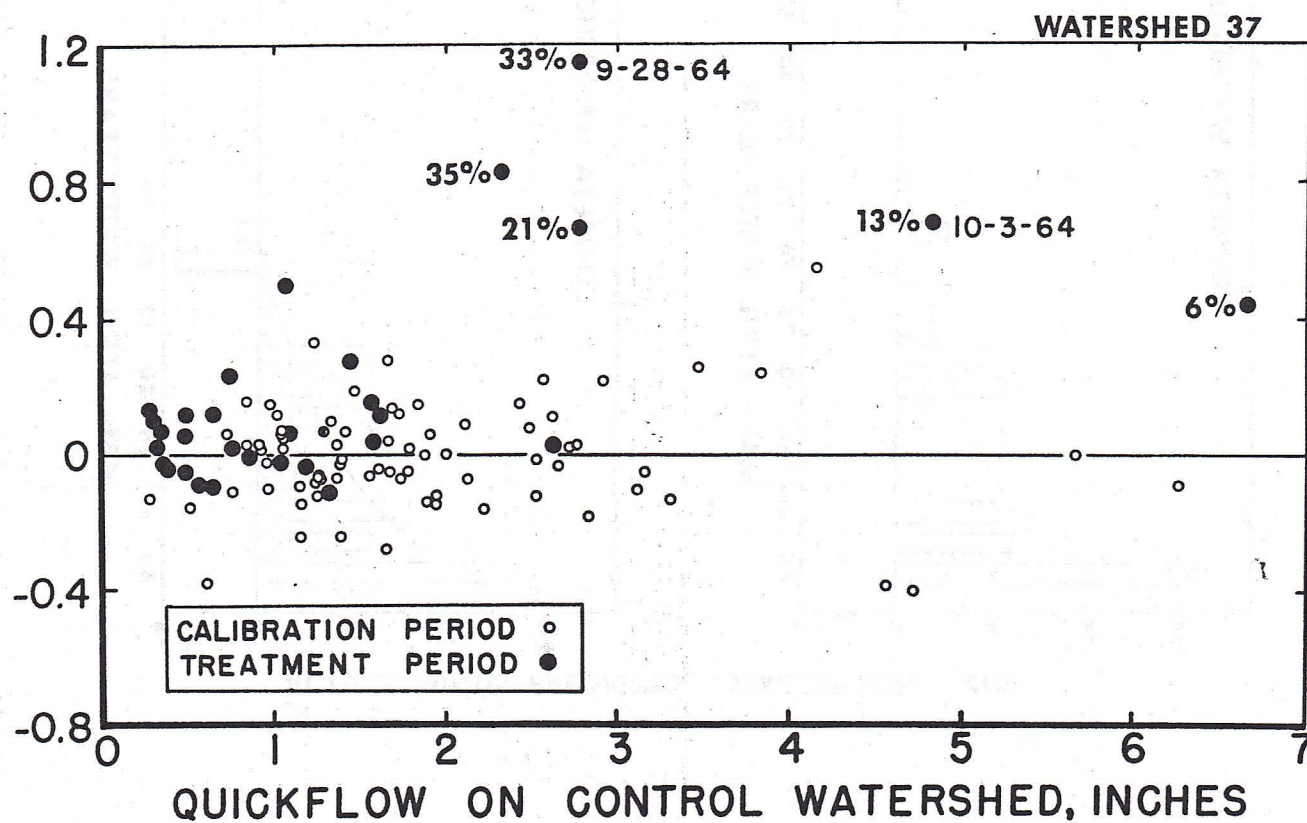


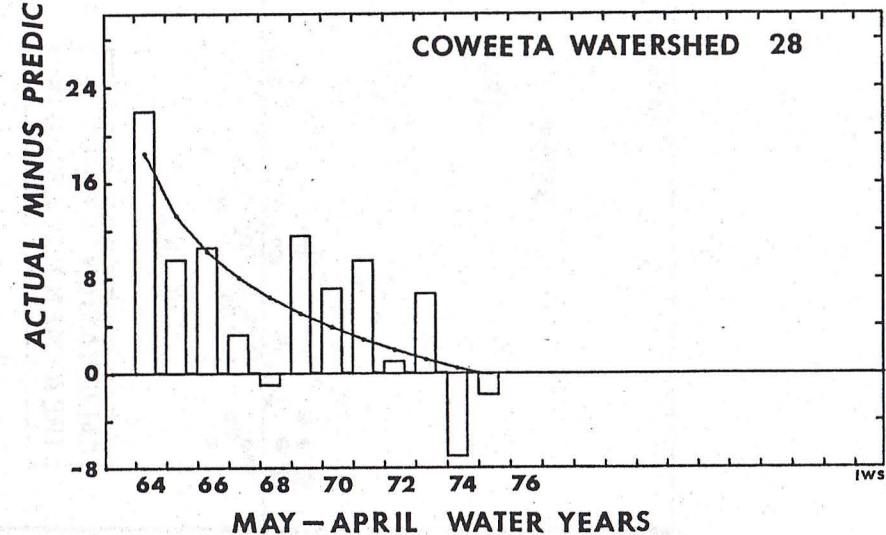
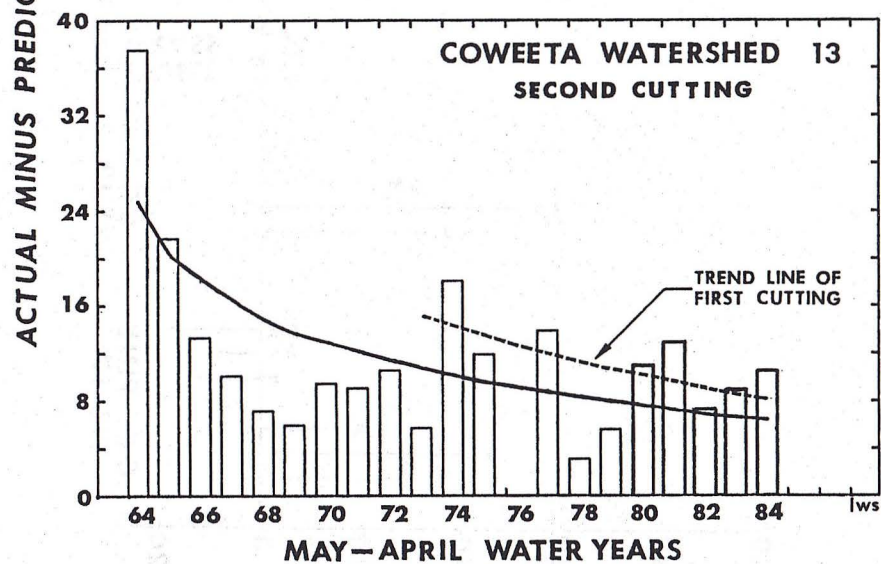
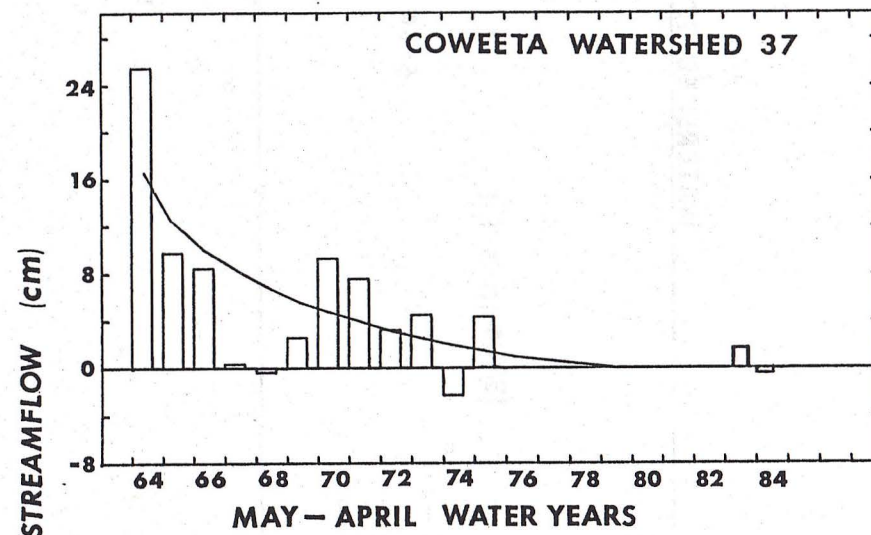
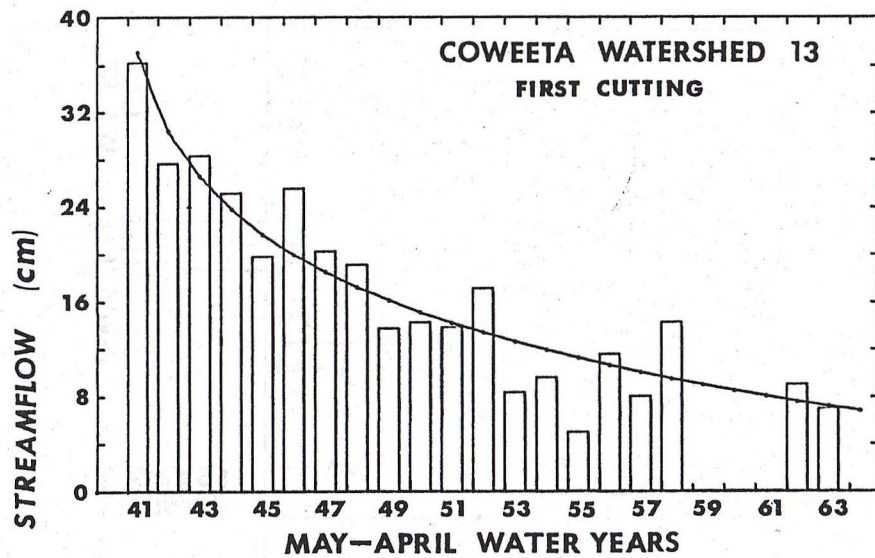
MONTHLY STREAMFLOW INCREASES

Averaged For Years When Regrowing Hardwood Forest
Was Recut Annually



QUICKFLOW DEVIATIONS FROM REGRESSION
ON TREATED WATERSHED, INCHES



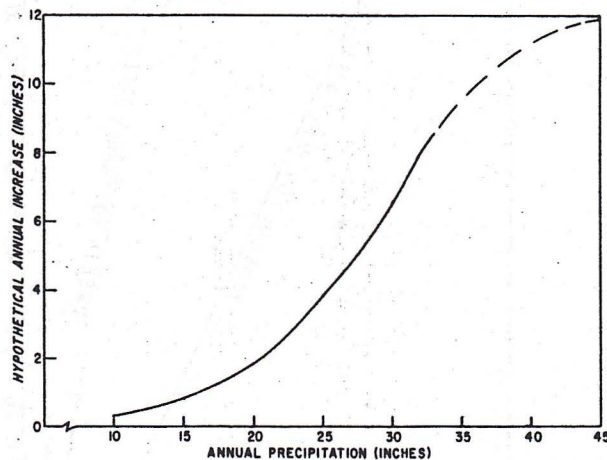


WATERSHED 13

- 1) Repeated cutting of a mixed hardwood forest yielded similar, large, first-year increases of streamflow.
- 2) Rapidly regrowing vegetation, possibly conditioned and selected by competition during the first regrowth period, reduced streamflow increases after the second cutting.
- 3) The decline of increases with time is the same for both regrowth periods.
- 4) Variation of individual annual increases around the trend line may be related to growing season precipitation and temperature.

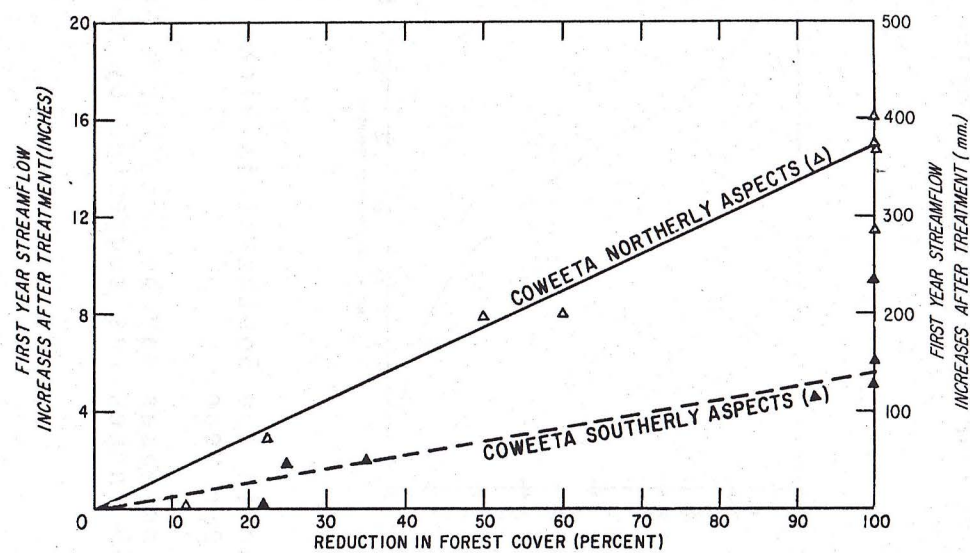
WATERSHED 37 AND WATERSHED 28

- 1) Smaller streamflow increases were found when high-elevation forests were cut.
- 2) The decline of increases with time for both watersheds is the same as found on Watershed 13.
- 3) Annual increases deviate in the same direction in the same years, suggesting common response to climate.

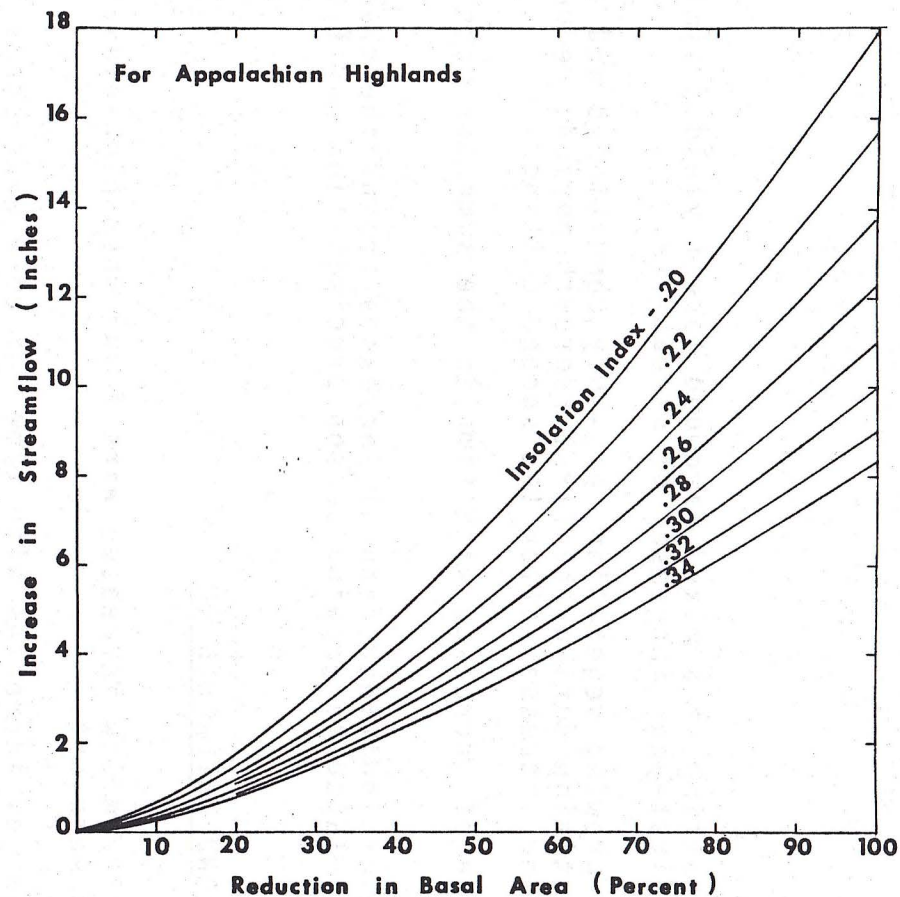


- 1) Precipitation in the Southeast is high; Coweeta averages 80 inches per year.
- 2) Streamflow increases may be less where annual precipitation is under 45 inches, as suggested by this hypothetical curve.

FIRST YEAR STREAMFLOW INCREASES AFTER CUTTING
SOUTHFACING SLOPES ARE ABOUT ONE-THIRD THOSE
FOUND FOR NORTHFACING SLOPES,



CHANGE IN ANNUAL STREAMFLOW TOTAL
AFTER CUTTING
MATURE, UNEVEN-AGED HARDWOOD FOREST

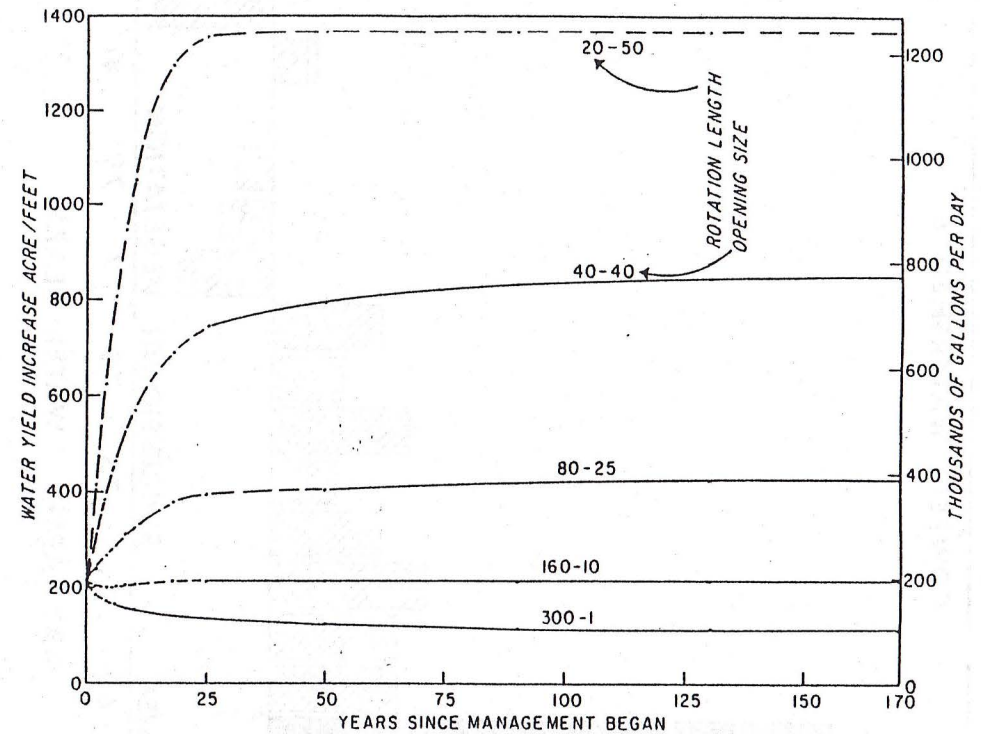
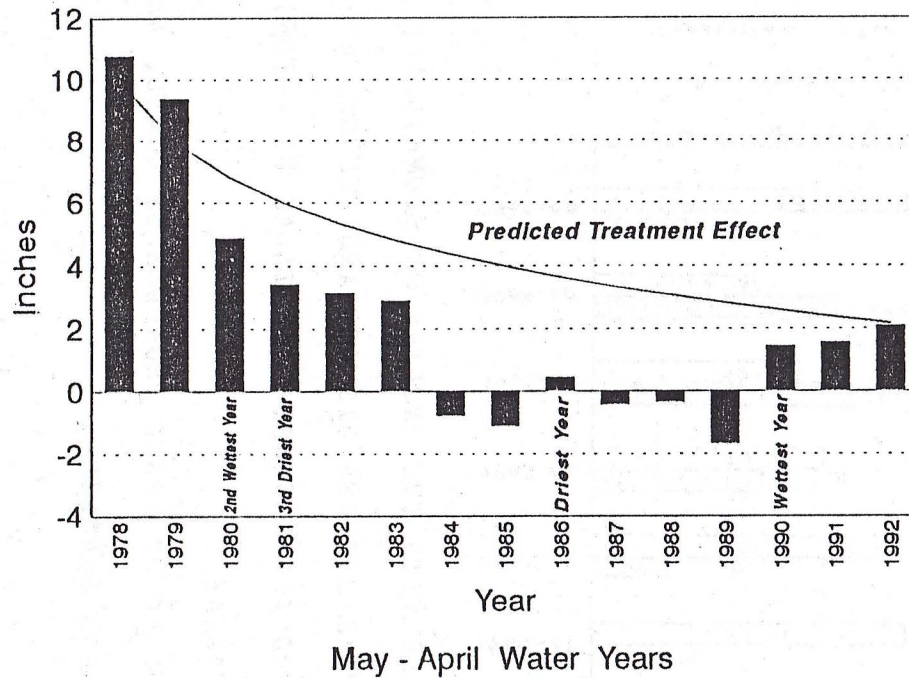


Flow Increase = First-Year Increase - 6.64 Log(Year)
Where Year = 1 in Year Cut, 2 in Next Year, Etc.

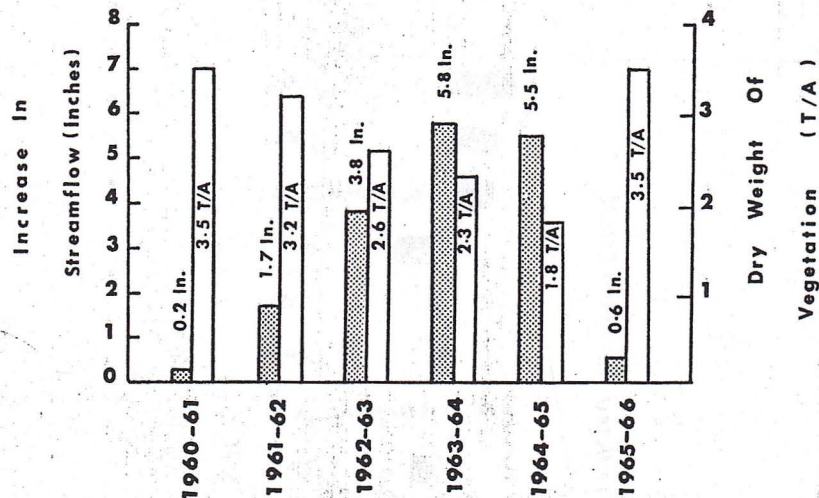
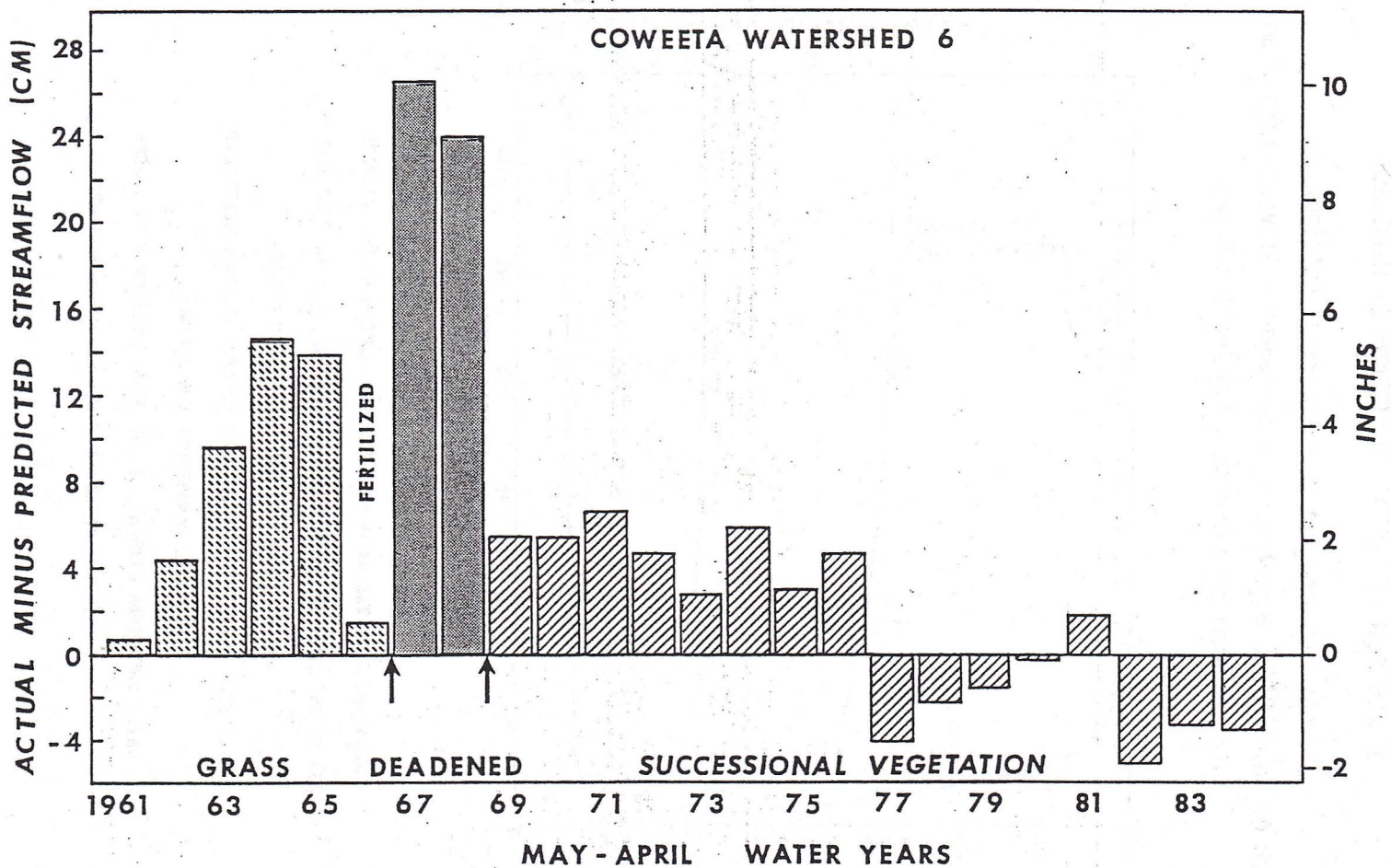
DEVELOPMENT OF SUSTAINED STREAMFLOW INCREASES

Predicted for Five Intensities of Cutting,
Each of Which Might be Selected to Implement a Silvicultural Plan
for an Unmanaged Southern Appalachian Forest

Watershed #7 Actual minus Estimated Streamflow

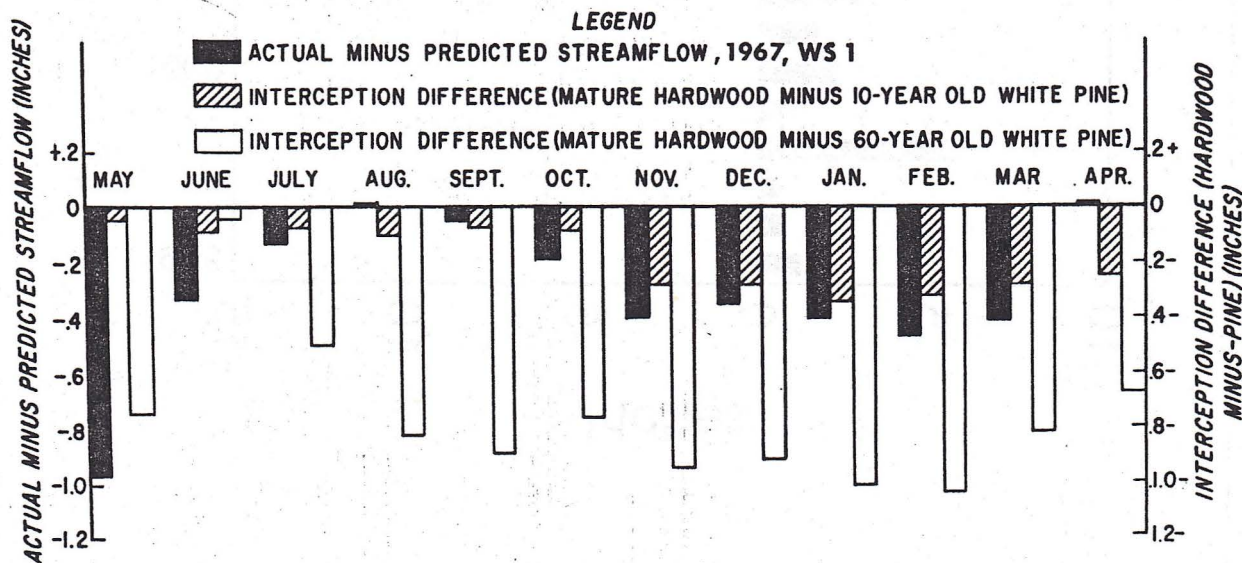
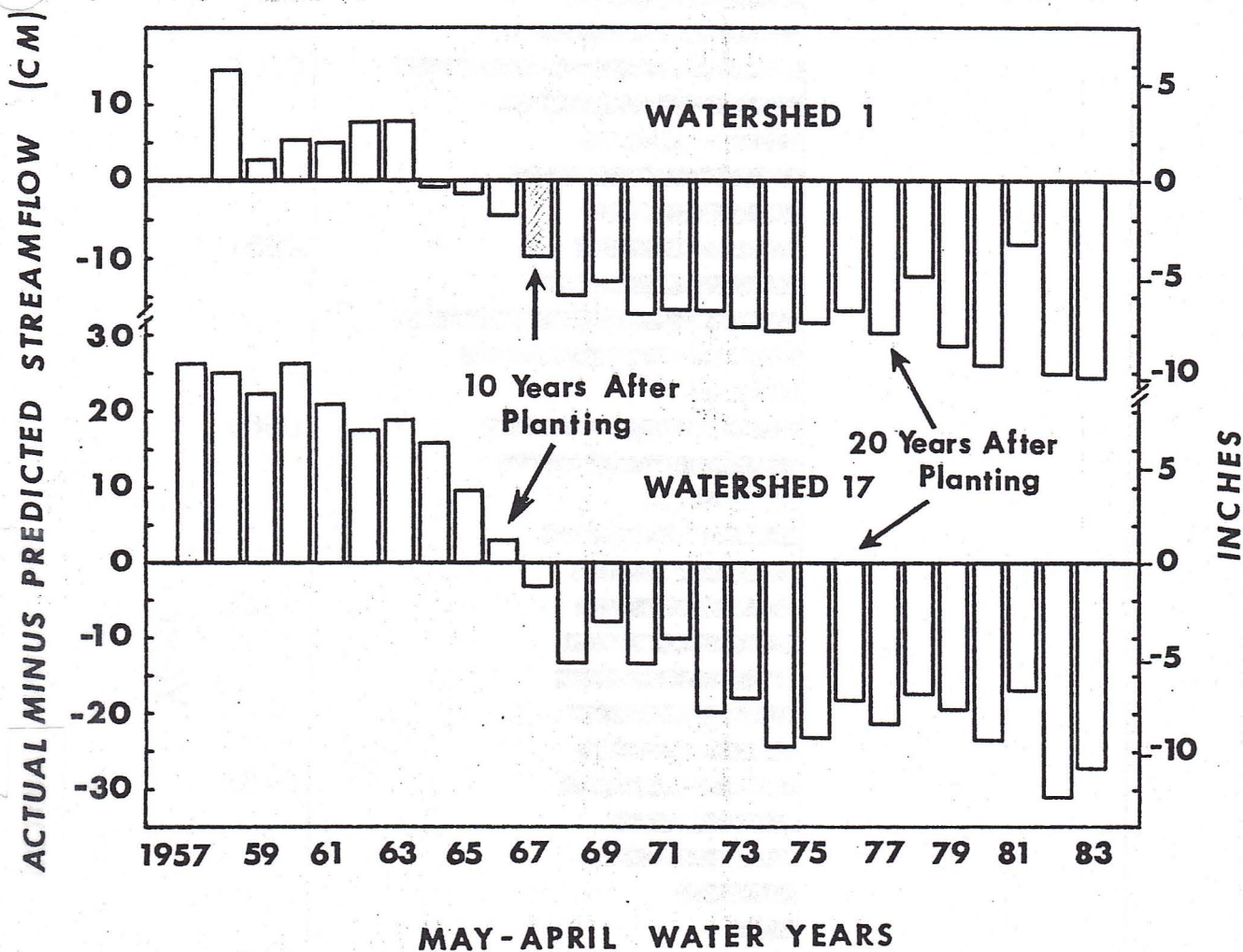


MANAGEMENT OF THE 6400-ACRE BIG IVY WATERSHED BEGINS WITH
23% OF THE LAND IN SEEDLINGS AND SAPLINGS, 69% IN POLE TIMBER
AND 8% IN MATURE AND OLD-GROWTH TIMBER.
A 20-YEAR ROTATION WITH 50-ACRE CLEARCUTS MIGHT REPRESENT
INTENSIVE MANAGEMENT FOR PULPWOOD
WHILE THE OTHER EXTREME, A 300-YEAR ROTATION WITH 1-ACRE
OPENINGS APPROACHES WILDERNESS MANAGEMENT.



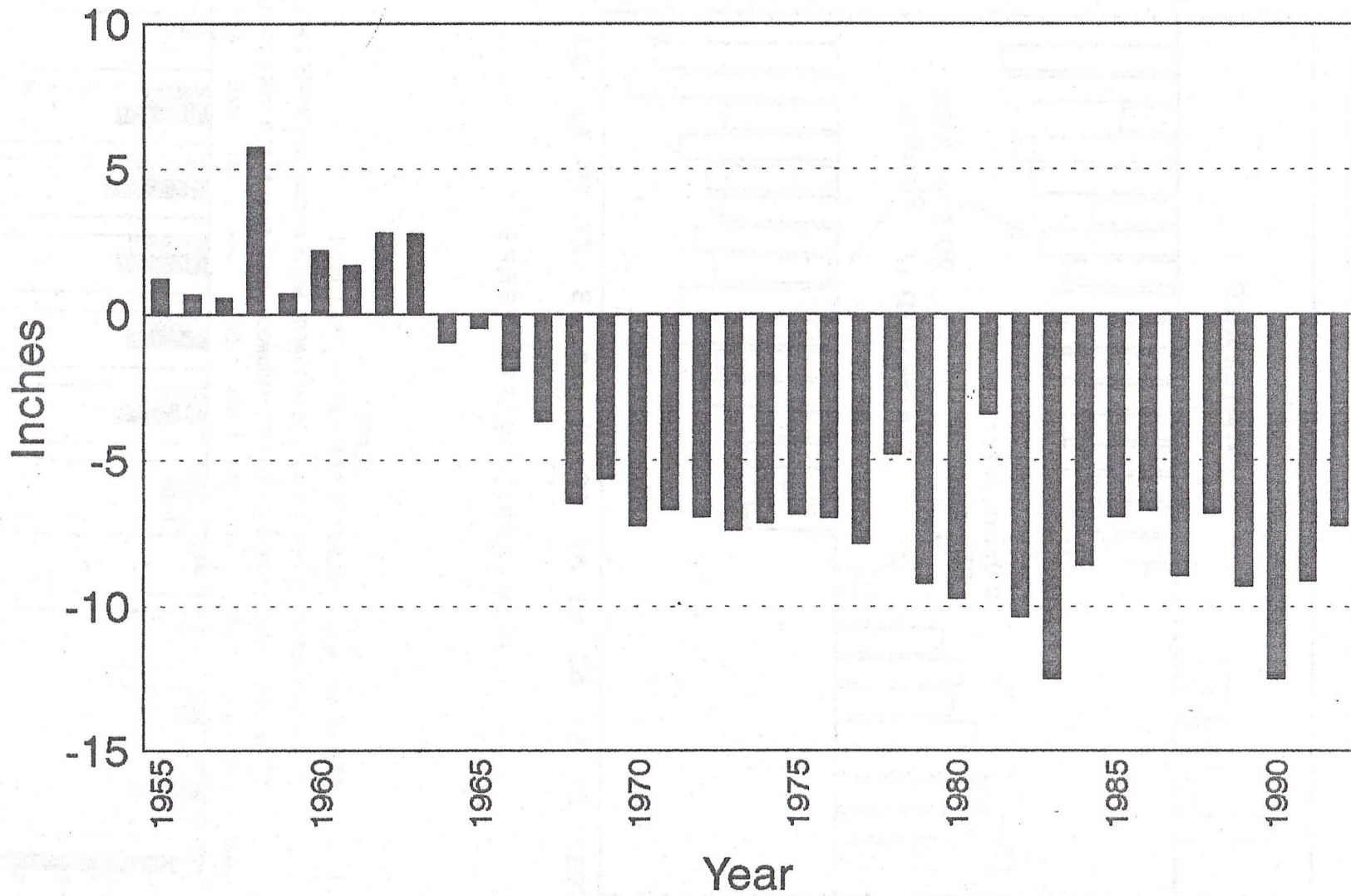
- 1) STREAMFLOW INCREASED WITH THE DECLINE OF BIOMASS FOR A KY-31 COVER.
- 2) FERTILIZATION INCREASED GRASS BIOMASS AND REDUCED STREAMFLOW.
- 3) STREAMFLOW INCREASED AFTER GRASS WAS KILLED BY WATER SPRAYS OF PARAQUAT AND ATRAZINE.
- 4) STREAMFLOW WAS REDUCED BY DENSE REGROWTH OF GRASS, HERBS, VINES, TREE SEEDLINGS, AND SPROUTS.

DECLINE OF ANNUAL STREAMFLOW AFTER PLANTING WHITE PINE ON SOUTHFACING WS 1 AND NORTHFACING WS 17



Watershed #1

Actual Flow minus Estimated Flow



Water Year May - April

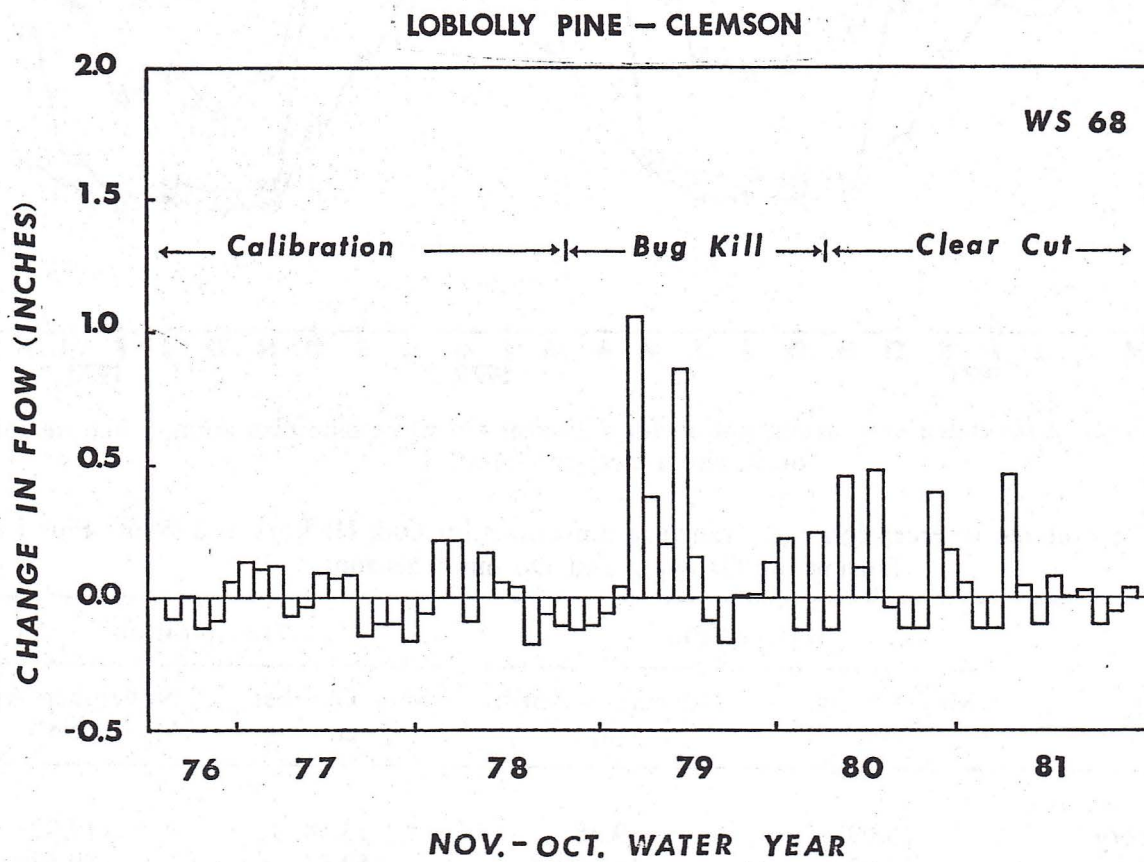
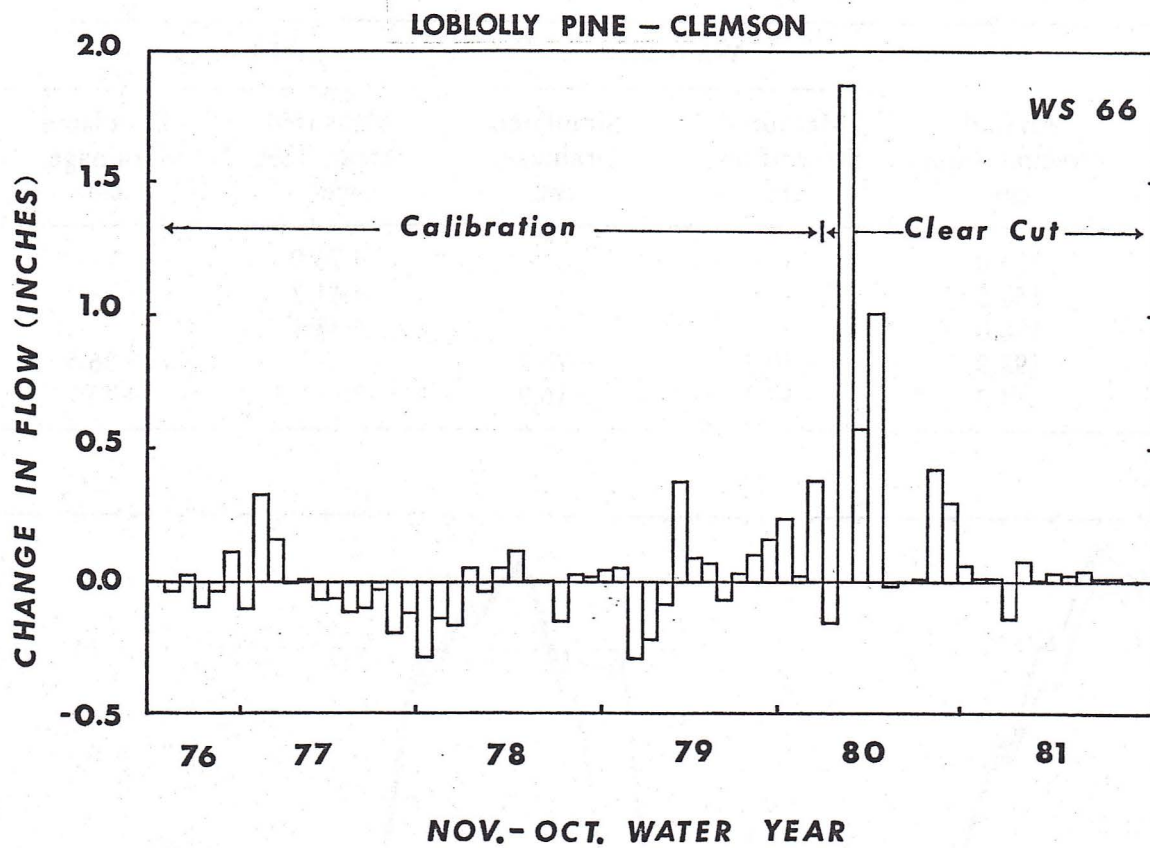


TABLE 4. Change in Annual Streamflow Attributable to Conversion From Mature Oak-Hickory Forest

Water Year May–April	Annual Precipitation, cm	White Pine		Clear-Cut	
		Measured Streamflow, cm	Simulated Drainage, cm	Measured Streamflow, cm	Simulated Drainage, cm
1940–1941	154.0	+36.0	...
1941–1942	158.5	+41.3	...
1963–1964	196.0	+38.1	...
1971–1972	198.9	–20.2	–20.2	...	+36.5
1972–1973	234.3	–18.3	–16.9	...	+42.2

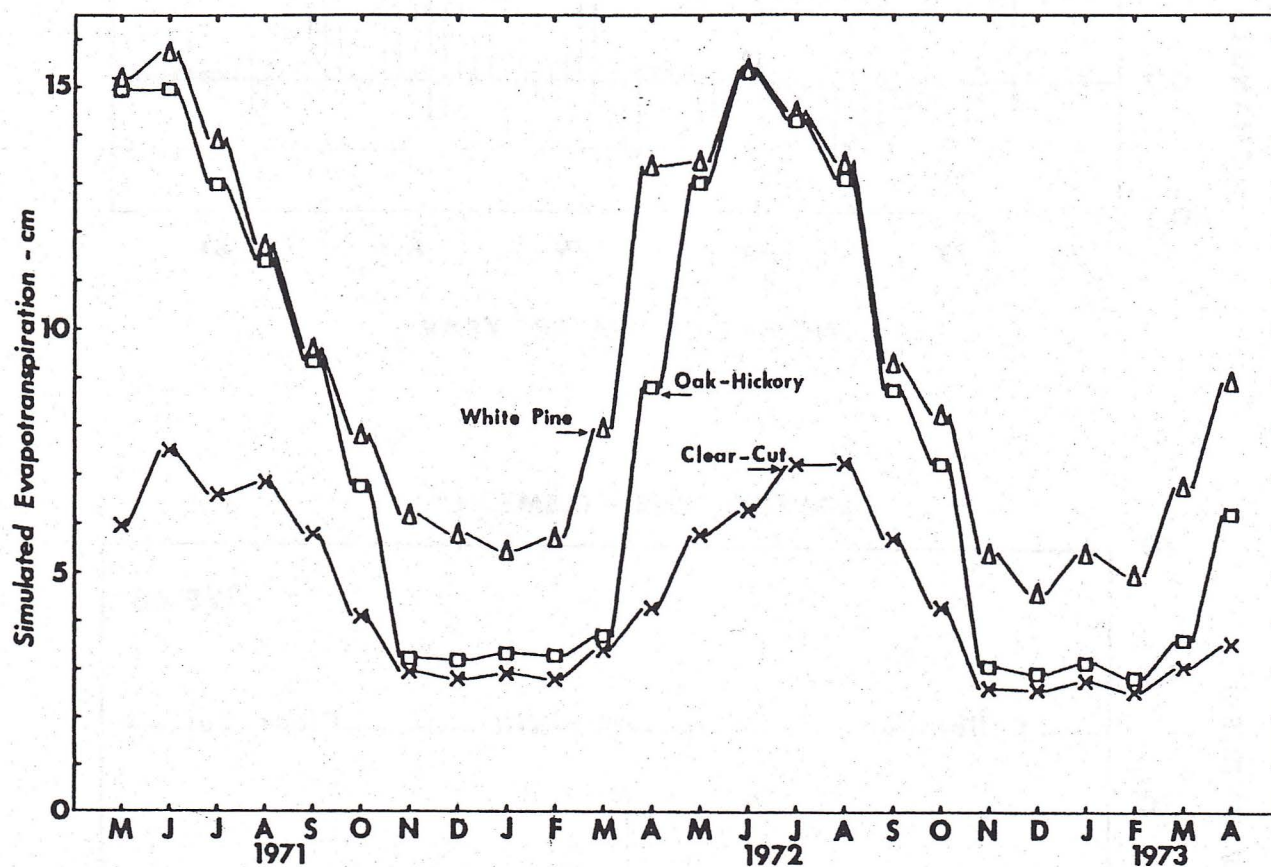
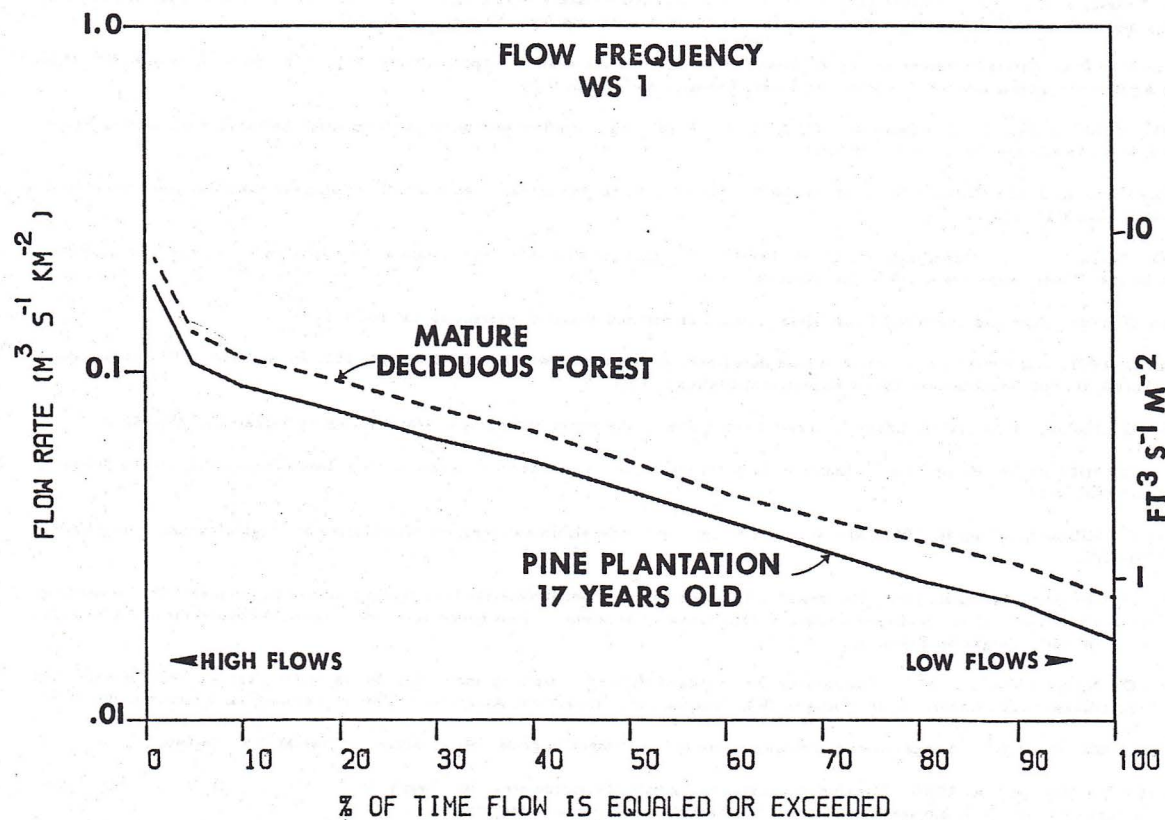
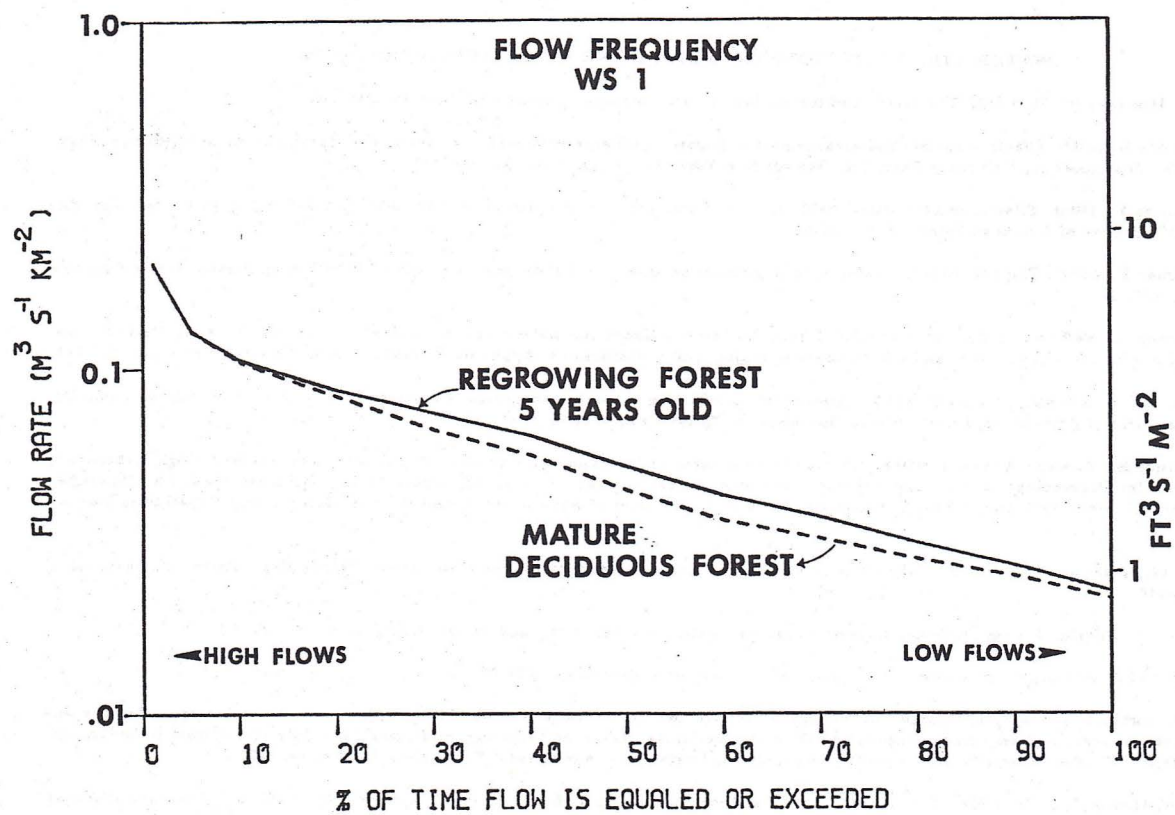


Fig. 2. Monthly totals of simulated evapotranspiration for a 16-year-old white pine plantation, a mature oak-hickory forest, and a clear-cut forest.

TABLE 5. Simulated Interception and Transpiration Totals for Oak-Hickory and White Pine Forests During the Growing and Dormant Seasons

Year and Vegetation Type	Interception		Transpiration	
	May–October, cm	November–April, cm	May–October, cm	November–April, cm
1971–1972				
Oak-hickory	15.09	9.38	53.54	13.02
White pine	20.07	14.16	52.64	29.53
1972–1973				
Oak-hickory	13.83	9.01	56.05	9.98
White pine	18.28	13.64	54.68	21.84



WATER YIELD CITATIONS OF WORK DONE AT OR ABOUT COWEETA

- Croft, A. R.; Hoover, M. D. 1951. The relation of forests to our water supply. *Journal of Forestry* 49: 245-249.
- Douglass, James E. 1966. Effects of species and arrangement of forests on evapotranspiration. In: *International symposium of forest hydrology*; 1965 August 29 - September 10; University Park, PA. Oxford; New York: Pergamon Press: pp. 451-461.
- Douglass, James E. 1980. Silviculture for water yield. In: *Town meeting forestry - issues for the 1980's*; 1979 October 15-19; Boston, MA. Washington, DC: Society of American Foresters: pp. 90-96.
- Douglass, James E. 1983. The potential for water yield augmentation from forest management in the Eastern United States. *Water Resource Bulletin* 19(3): 351-358.
- Douglass, James E. 1983. A summary of some results from the Coweeta Hydrologic Laboratory. In: Hamilton, Lawrence S.; King, Peter N., eds. *Tropical forested watersheds: hydrologic and soil response to major uses or conversions*. Appendix B. Boulder, CO: Westview Press: pp. 137-141.
- Douglass, James E.; Swank, Wayne T. 1972. Streamflow modification through management of eastern forests. Res. Pap. SE-94. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 15 pp.
- Douglass, James E.; Swank, Wayne T. 1975. Effects of management practices on water quality and quantity: Coweeta Hydrologic Laboratory, North Carolina. In: *Proceedings of the municipal watershed management symposium*; 1973 September 11-12; University Park, PA; September 19-20; Durham, NH. Gen. Tech. Rep. NE-13. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Experiment Station: pp. 1-13.
- Dunford, E. G.; Fletcher, P. W. 1947. Effect of removal of stream-bank vegetation upon water yield. *Transactions, American Geophysical Union* 28: 105-110.
- Evans, James O.; Patric, James H. 1983. Harvest trees, reap water. *Journal of Soil and Water Conservation* 38: 390-392.
- Helvey, J. D. 1967. Interception by eastern white pine. *Water Resources Research* 3: 723-729.
- Helvey, J. D. 1971. A summary of rainfall interception by certain conifers of North America. In: Monke, E. J., ed. *Biological effects in the hydrological cycle-terrestrial phase: proceedings of the third international seminar for hydrology professors*; 1971 July 18-30; West Lafayette, IN. West Lafayette, IN: Purdue University, Department of Agricultural Engineering, Agricultural Experiment Station: pp. 103-113.
- Helvey, J. D.; Hewlett, J. D. 1962. The annual range of soil moisture under high rainfall in the Southern Appalachians. *Journal of Forestry* 60: 485-486.
- Helvey, J. D.; Patric, J. H. 1965. Canopy and litter interception of rainfall by hardwoods of eastern United States. *Water Resources Research* 1: 193-206.
- Helvey, J. D.; Patric, J. H. 1988. Research on interception losses and soil moisture relationships. In: Swank, W. T.; Crossley, D. A., Jr., eds. *Forest hydrology and ecology at Coweeta*. Ecological Studies, vol. 66. New York: Springer-Verlag: pp. 129-137.
- Helvey, Junior D. 1964. Rainfall interception by hardwood forest litter in the southern Appalachians. Res. Pap. SE-8. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 9 pp.
- Hewlett, J. D.; Cunningham, G. B.; Troendle, C. A. 1977. Predicting stormflow and peakflow from small basins in humid areas by the R-index method. *Water Resources Research* 13: 231-253.
- Hewlett, J. D.; Fortson, J. C.; Cunningham, G. B. 1977. The effect of rainfall intensity on storm flow and peak discharge from forest land. *Water Resources Research* 13: 259-265.
- Hewlett, J. D.; Fortson, J. C.; Cunningham, G. B. 1984. Additional tests on the effect of rainfall intensity on storm flow and peak flow from wild-land basins. *Water Resources Research* 20: 985-989.
- Hewlett, John D. 1958. Pine and hardwood forest yield. *Journal of Soil and Water Conservation* 13: 106-109.
- Hewlett, John D. 1961. Soil moisture as a source of base flow from steep mountain watersheds. Stn. Pap. 132. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 11 pp.
- Hewlett, John D.; Helvey, J. D. 1970. Effects of forest clear-felling on the storm hydrograph. *Water Resources Research* 6: 768-782.
- Hewlett, John D.; Hibbert, A. R. pp. 1961. Increases in water yield after several types of forest cutting. *International Association Scientific Hydrology Bulletin* 6(3): 5-17.
- Hewlett, John D.; Hibbert, Alden R. 1963. Moisture and energy conditions within a sloping soil mass during drainage. *Journal of Geophysical Research* 68: 1081-1087.
- Hewlett, John D.; Hibbert, Alden R. 1966. Factors affecting the response of small watersheds to precipitation in humid areas. In: *Proceedings of a National Science Foundation advanced science seminar, international symposium of forest hydrology*; 1965 August 29 - September 10; University Park, PA. Oxford; New York: Pergamon Press: pp. 275-290.
- Hewlett, John D.; Nutter, Wade L. 1970. The varying source area of streamflow from upland basins. In: *Interdisciplinary aspects of watershed management: Proceedings of the symposium*; 1970 August 3-6; Bozeman, MT. New York: American Society of Agricultural Engineers: pp. 65-83.
- Hibbert, A. R. 1969. Water yield changes after converting a forested catchment to grass. *Water Resources Research* 5: 634-640.
- Hibbert, A. R.; Troendle, C. A. 1988. Streamflow generation by variable source area. In: Swank, W. T.; Crossley, D. A., Jr., eds. *Forest hydrology and ecology at Coweeta*. Ecological Studies, vol. 66. New York: Springer-Verlag: pp. 111-127.

- Hibbert, Alden R. 1966. Forest treatment effects on water yield. In: Proceedings of a National Science Foundation advanced science seminar, international symposium on forest hydrology; 1965 August 29 - September 10, University Park, PA. Oxford, New York: Pergamon Press: pp. 527-543.
- Hoover, M. D. 1944. Effect of removal of forest vegetation upon water yields. Transactions, American Geophysical Union. Part 6: 969-977.
- Hoover, M. D.; Hursh, C. R. 1943. Influence of topography and soil depth on runoff from forest land. Transactions, American Geophysical Union, Part 2: 693-698.
- Huff, D. D.; Swank, W. T. 1985. Modeling changes in forest evapotranspiration. In: Anderson, M. G.; Burt, T. P., eds. Hydrological forecasting. Chichester: John Wiley & Sons: pp. 125-151.
- Hursh, C. R.; Hoover, M. D.; Fletcher, P. W. 1942. Studies in the balanced water-economy of experimental drainage-areas. Transactions, American Geophysical Union. Part 2: 509-517.
- Johnson, E. A.; Kovner, J. L. 1954. Increasing water yield by cutting forest vegetation. Georgia Mineral Newsletter 7(4): 145-148.
- Johnson, E. A.; Meginnis, H. G. 1960. Effect of altering forest vegetation on low flows of small streams. In: 12th general assembly International Union of Geodesy and Geophysics, International Association of Scientific Hydrology; 1960 July 25 - August 6; Helsinki, Finland. Publication 51. Washington, DC: International Association of Scientific Hydrology: pp. 257-266.
- Johnson, Edward A.; Kovner, Jacob L. 1956. Effect on streamflow of cutting a forest understory. Forest Science 2: 82-91.
- Kovner, J. L. 1957. Evapotranspiration in forest stands of the southern Appalachian Mountains. Bulletin of the Georgia Academy of Science 15(3): 80-85.
- Kovner, Jacob L. 1957. Evapotranspiration and water yields following forest cutting and natural regrowth. pp. 106-110. Proceedings, Society of American Foresters; 1956; Memphis, TN. Washington, DC: Society of American Foresters.
- Lieberman, J. A.; Fletcher, P. W. 1947. Further studies of the balanced water cycle on experimental watersheds. Transactions, American Geophysical Union 28: 421-424.
- Lieberman, J. A.; Hoover, M. D. 1951. Stream-flow frequency changes on Coweeta experimental watersheds. Transactions, American Geophysical Union 32: 73-76.
- Luvall, J. C. 1988. Using the TIMS to estimate evapotranspiration from a white pine forest. In: Remote sensing for resource inventory, planning, and monitoring; The 2nd Forest Service remote sensing applications conference; 1988 April 11-15; National Space Technology Laboratories, MS: pp. 90-98. [Available from National Space Technology Laboratories, MS]
- McMinn, Jane W.; Hewlett, John D. 1975. First-year yield increase after forest cutting: an alternative model. Journal of Forestry 73(10): 654-655.
- Meginnis, H. G. 1959. Increasing water yields by cutting forest vegetation. In: Woodlands and water-lysimeters: Symposium, International Union of Geodesy and Geophysics. International Association of Scientific Hydrology; 1959 September 8-13; Hannoversch- Munden, Germany. Publication 48. Gerdbrugge, Belgium: International Association of Scientific Hydrology: pp. 59-68.
- Moore, Allen; Swank, Wayne T. 1975. A model of water content and evaporation for hardwood leaf litter. In: Howell, Fred G.; Gentry, John B.; Smith, Michael H., eds. Mineral cycling in southeastern ecosystems; U.S. Energy Research and Development Administration Symposium Series (Conf-740513); 1974 May 1-3; Augusta, GA. Springfield, VA: Technical Information Center, Office of Public Affairs: pp. 58-69.
- Murphy, Charles E., Jr.; Knoerr, Kenneth R. 1975. The evaporation of intercepted rainfall from a forest stand: an analysis by simulation. Water Resources Research 11(2): 273-280.
- Nutter, Wade L. 1973. The role of soil water in the hydrologic behavior of upland basins. In: Field soil science regime; 1971 August 15-20; New York. Madison, WI: Soil Science Society of America: pp. 181-193.
- Nutter, Wade L. 1975. Moisture and energy conditions in a draining soil mass. Technical Completion Report, ERC 0875. Athens, GA: University of Georgia, School of Forest Resources. 77 pp.
- Patric, James H.; Douglass, James E.; Hewlett, John D. 1965. Soil water absorption by mountain and piedmont forests. Proceedings, Soil Society of America 29: 303-308.
- Penman, H. L. 1956. Estimating evaporation. Transactions, American Geophysical Union 37(1): 43-50.
- Scholl, David G.; Hibbert, Alden R. 1973. Unsaturated flow properties used to predict outflow and evaporation from a sloping lysimeter. Water Resources Research 9(6): 1645-1655.
- Sloan, P. G.; Moore, I. D.; Coltharp, G. B.; Eigel, J. D. 1983. Modeling surface and subsurface stormflow on steeply-sloping forested watersheds. Research Report 142. Water Resources Research Institute, University of Kentucky, Lexington. 167 pp.
- Sloan, Patrick G., Moore Ian D. 1984. Modeling subsurface stormflow on steeply sloping forested watersheds. Water Resources Research 20(12): 1815-1822.
- Stagnitti, F.; Parlange, M. B.; Steenhuis, T. S.; Parlange, J.-Y. 1986. Drainage from a uniform soil layer on a hillslope. Water Resources Research 22(5): 631-634.
- Stone, E. L.; Swank, W. T.; Hornbeck, J. W. 1980. Impacts of timber harvest and regeneration systems on stream flow and soils in the eastern deciduous region. In: Forest soils and land use: Proceedings of the fifth North American forest soils conference; 1978 August; Fort Collins, CO. Fort Collins, CO: Colorado State University, Department of Forest and Wood Sciences: pp. 516-535.

Swank, W. T. 1968. The influence of rainfall interception on streamflow. In: Proceedings, hydrologic water resource management conference; 1968 March 28-29; Clemson, SC. Rep. 4. Clemson, SC: Clemson University Water Resources Research Institute: pp. 101-112.

Swank, W. T. 1972. Soils and water. In: Wade, Larkin, ed. Social and political influence in the managed forest: Proceedings of the eleventh Auburn forestry forum; 1972 December; Auburn, AL. Auburn, AL: Cooperative Extension Service, Auburn University: pp. 51-58.

Swank, W. T.; Douglass, J. E.; Cunningham, G. B. 1982. Changes in water yield and storm hydrographs following commercial clearcutting on a Southern Appalachian catchment. In: Hydrological research basins and their use in water resource planning: proceedings of the international symposium; Vol. 2. 1982 September 21-23; Berne, Switzerland. Berne, Switzerland: Landeshydrologie. pp. 583-594.

Swank, W. T.; Helvey, J. D. 1970. Reduction of streamflow increases following regrowth of clearcut hardwood forests. In: Symposium on the results of research on representative and experimental basins; 1970 December; Wellington, New Zealand. Publication 96. Leuven, Belgium: United Nations Educational, Scientific and Cultural Organization - International Association of Scientific Hydrology: pp. 346-360.

Swank, W. T.; Miner, N. H. 1968. Conversion of hardwood-covered watersheds to white pine reduces water yield. Water Resources Research 4: 947-954.

Swank, W. T.; Swift, L. W., Jr.; Douglass, J. E. 1988. Streamflow changes associated with forest cutting, species conversions, and natural disturbances. In: Swank, W. T.; Crossley, D. A., Jr., eds. Forest hydrology and ecology at Coweeta. Ecological Studies, vol. 66. New York: Springer-Verlag: pp. 297-312.

Swank, Wayne T.; Crossley, D. A., Jr., eds. 1988. Forest hydrology and ecology at Coweeta. Ecological Studies, vol. 66. New York: Springer-Verlag. 469 pp.

Swank, Wayne T.; DeBano, Leonard F.; Nelson, Devon. 1989. Effects of timber management practices on soil and water. In: Burns, Russel L., technical compiler. The scientific basis for silvicultural and management decisions in the national forest system. Gen. Tech. Rep. WO-55. Washington, D.C.: U.S. Department of Agriculture, Forest Service: pp. 79-106.

Swank, Wayne T.; Douglass, James E. 1974. Streamflow greatly reduced by converting deciduous hardwood stands to pine. Science 185: 857-859.

Swank, Wayne T.; Goebel, Norbert B.; Helvey, Junior D. 1972. Interception loss in loblolly pine stands of the South Carolina Piedmont. Journal of Soil and Water Conservation 27: 160-164.

Swift, Lloyd W., Jr. 1976. Algorithm for solar radiation on mountain slopes. Water Resources Research 12: 108-112.

Swift, Lloyd W., Jr. 1983. Green sponge. The American Tree Farmer 2(5): 7.

Swift, Lloyd W., Jr.; Swank, Wayne T. 1981. Long term responses of streamflow following clearcutting and regrowth. Hydrological Sciences Bulletin 26: 245-256.

Swift, Lloyd W., Jr.; Swank, Wayne T.; Mankin, J. B.; Luxmoore, R. J.; Goldstein, R. A. 1975. Simulation of evapotranspiration and drainage from mature and clear-cut deciduous forests and young pine plantation. Water Resources Research 11(5): 667-673.

Swindel, Bennee F.; Douglass, James E. 1984. Describing and testing nonlinear treatment effects in paired watershed experiments. Forest Science 30(2): 305-313.

Troendle, Charles A. 1979. Hydrologic impacts of silvicultural activities. Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers; vol. 105 (No. IR 1): 57-70.

Ursic, Stanley J.; Douglass, James E. 1979. The effects of forestry practices on water resources. In: Proceedings of the W. Kelly Mosley environmental forum; 1978 May; Auburn, AL. Auburn, AL: Auburn University Press: pp. 33-49.

Waring, R. H.; Rogers, James J.; Swank, W. T. 1980. Water relations and hydrologic cycles. In: Reichle, D. E., ed. Dynamic properties of forest ecosystems. Malta: Cambridge University Press: pp. 205-264.